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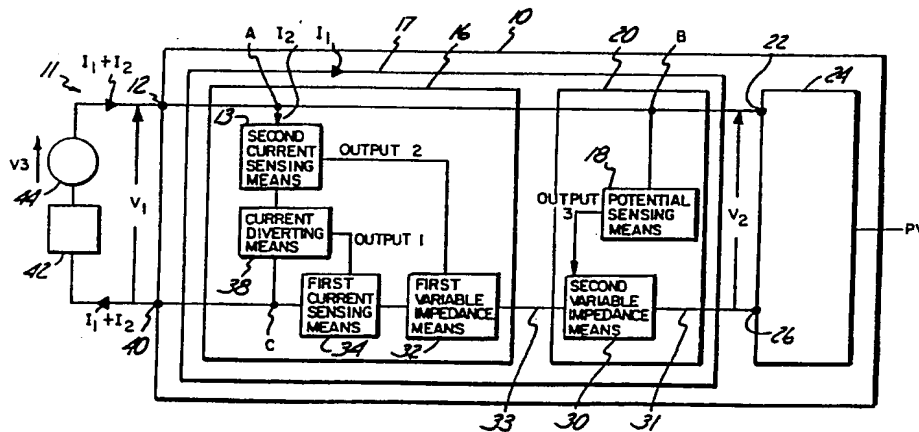
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With international search report.

(54) Title: PROCESS CONTROL INSTRUMENT WITH LOOP OVERCURRENT CIRCUIT

(57) Abstract

A process control instrument (10) receiving a DC current from a two wire loop (11, 43) having overcurrent protection (16, 52) and reverse current protection (20, 54) circuits interposed between a two wire loop (11, 43) and a process control device (24) for reducing the incidence of damage or degradation to the process control device (24) from excessive and reverse polarity currents from the loop. The overcurrent protection circuit (16, 52) comprises device current flowing through a first current sensing circuit (34, 60) which generates a first output which controls impedance of a current diverting circuit (38, 62). The impedance of the current diverting circuit controls the flow of a shunt current shunted back to the two wire loop (11, 43). Shunt current flowing through a second current sensing circuit (13, 50) generates a second output which controls impedance of a first variable impedance circuit (32, 70). The first variable impedance circuit (32, 70) conducts the device current and limits device current flowing through the process control device (24) to a predetermined range. A potential sensing circuit (18, 94) in the reverse current protection circuit (20, 54) senses a potential induced across the process control device (24) and generates a third output which is indicative of polarity of device current. The third output controls impedance of a second variable impedance circuit (30, 56) which also conducts the device current. The second variable impedance circuit (30, 56) reduces the flow of reverse current through the process control device (24) while having little effect on normal operation of the process control instrument (10).



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⁺ It is not yet known for which States of the former Soviet Union any designation of the Soviet Union has effect.

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PROCESS CONTROL INSTRUMENT
WITH LOOP OVERCURRENT CIRCUIT
BACKGROUND OF THE INVENTION

This invention relates to industrial process
5 control instruments such as pressure transmitters,
current to pressure (I/P) converters, and the like
having overcurrent and reverse current protection
circuits.

In industrial process control systems,
10 overcurrent and reverse current protection circuits
operate between a two-wire DC current loop and a process
control instrument. These protection circuits reduce
the incidence of damage or degradation to the process
15 control instrument from excessive and reverse polarity
currents from the loop. Examples of such process
control instruments include pressure, temperature, flow,
pH, conductivity and the like transmitters, are shown
for example in US-A 3975719, and current to pressure
20 converters, valve actuators and the like, are shown for
example in US-A 4481967, both assigned to the owner of
the present application.

Although a variety of operating ranges are
used, two wire transmitters and I/P's typically operate
in a loop current range of 4 to 20 mA, where loop
25 current flows in one continuous loop. Energization of
the loop is typically limited to a lower energy level
incapable of igniting a combustible atmosphere.
Therefore, since process control instruments operate
remotely from control centers, the potential drops
30 induced in each of the loop wires supplying loop current
and the process control instrument are critical in
determining a maximum wire length for remote operation
of the process control instrument. The application of

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process control instruments in the industrial process industry requires careful consideration of several system design parameters including lift-off potential of the process control instrument, which is desired to be reduced. Lift-off potential is a minimum potential necessary at an instrument to ensure that the process control instrument operates properly. Reducing potential drops of the overcurrent and reverse current protection circuits, each of which increase the lift-off potential of the process control instrument, allows for an increased potential drop in the loop wire thus increasing permissible wire length.

Some instruments include a diode in series with the two wire loop to block the flow of reverse current, as taught in US-A 3975719 and US-A 4783659 for two wire transmitters, both assigned to the owner of the present application. The diode produces a large potential drop in the instrument when current flows in the proper direction, which significantly increases the lift-off voltage and reduces the permissible wire length.

US-A 3975719 and US-A 4783659 also teach overcurrent protection circuits in two wire current transmitters. These Patents teach a resistor in series with the two wire loop and connected to the emitter of a transistor with one end of a Zener diode connected to a remote end of the resistor and the other end of the Zener diode connected to the base of the transistor. While this combination limits the maximum value of the loop current, a large potential drop is produced across the resistor during normal operation which further contributes to increasing the lift-off potential of the process control instrument.

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There is a need to provide a protection circuit that protects a process control instrument from large and reverse polarity currents from a loop where the currents can damage or degrade the instrument, while
5 reducing the potential drop in the loop thus reducing a lift-off potential of the instrument. Further, there is a need to provide a protection circuit which diverts substantially no current back to the loop during normal operation thus improving accuracy of the instrument, in
10 a simple, reliable and cost effective manner. A circuit that is substantially undamaged by either a decreased impedance or a short circuit of the two wire loop is desirable.

In the present invention, a process control
15 instrument includes overcurrent and reverse current protection circuits, having reduced potential drops and reduced leakage currents, to reduce incidence of damage or degradation to a process control instrument, such as a pressure, temperature, flow, pH, or conductivity
20 transmitter; or a current to pressure (I/P) converter, a valve actuator, or the like.

The overcurrent protection circuit receives a DC loop current from a two wire loop and passes a portion of the loop current through the process control
25 instrument as a device current. First current sensing means conducting the device current between the loop and the device provides a first output indicative of the device current amplitude. Current diverting means coupled across the two wire loop responds to the first
30 output when device current flows at an upper limit by diverting a portion of the loop current back to the loop as a shunt current. Second current sensing means conducts the shunt current and provides a second output

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indicative of the shunt current amplitude. First impedance means having a first variable impedance conducting the device current responds to the second output by varying the first impedance to limit the device current to no greater than a predetermined upper limit.

The reverse current protection circuit conducts the device current between the loop and the process control device and responds to the loop potential. The circuit has second impedance means having a second variable impedance for inhibiting the device current from flowing through the device when the loop potential is reversed from a predetermined polarity. The circuit diverts substantially no device current back to the loop when loop potential comprises a proper polarity and loop current is within the predetermined normal range.

Reference is made to the drawings wherein:

FIG. 1 is a block diagram representation of a first embodiment of a two-wire process control instrument having an overcurrent and reverse current protection circuit according to the present invention; and

FIG. 2 is a schematic representation of a second embodiment of a process control instrument having an overcurrent and reverse current protection circuit according to the invention.

Referring to FIG. 1 a block diagram of a first embodiment of two-wire process control instrument 10 is shown. Instrument 10 is wired in series with power source 44 and a separate process control device 42 to form two-wire loop 11 carrying a DC loop current. Under fault conditions, loop current or voltage in such

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instruments can exceed a predetermined normal range, e.g. 0-60 mA for a 4-20 mA loop where 60 mA is an upper limit, which would damage or degrade performance of process control device 24, such as a pressure transmitter. To reduce incidence of damage or degradation to process control device 24 from excessive and reverse polarity current, instrument 10 includes protection circuit 17 coupling current from loop 11 to device 24. Protection circuit 17 receives DC loop current $I_1 + I_2$ and passes only normal current or device current I_1 of the loop current on to device 24. Circuit 17 limits device current I_1 to a level in the normal range which prevents or reduces degradation of device 24. The remainder of the loop current, shunt current or overcurrent I_2 , is shunted back to loop 11 for controlling the level of device current I_1 . Shunt current I_2 is substantially zero until amplitude of normal current I_1 attains the upper limit in the normal range.

Process control device 24, such as a pressure transmitter as disclosed, senses process variable "PV" as illustrated in FIG. 1. Process control device 24 controls amplitude of variable normal current I_1 as a function of amplitude of process variable PV and process control device 42 functions as a current sensing instrument, such as a recorder, by sensing amplitude of loop current $I_1 + I_2$, and correlating loop current amplitude to the process variable PV.

On the other hand, process control device 24 can be an output device, such as a current-to-pressure(I/P) converter or a current-to-position converter. In this embodiment, the separate process current control device 42, such as a controller,

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controls amplitude of loop current I_1+I_2 , and process control device 24 controls the magnitude of its output, process variable PV, as a function of amplitude of variable normal current I_1 .

5 The process control device 24 can also include a circuit for generating and receiving a time-varying-signal sent over loop 11 such as taught in US-A 4665938 to Brown et al.

10 The present invention is suitable for use in a process control system utilizing multidrop process instruments, such as pressure transmitters, each connected in parallel across a two wire loop and processing information by superimposing digital data over a DC line.

15 Loop 11 provides loop current I_1+I_2 to terminal 12 in instrument 10, which returns loop current to loop 11 from terminal 40 in instrument 10. In instrument 10, overcurrent protection circuit 16 and reverse current protection circuit 20 isolate process
20 control device 24 from excessive currents from the loop 11. Loop current I_1+I_2 flows from terminal 12 to node A in overcurrent protection circuit 16. At node A, any overcurrent I_2 flows to current sensing means 13, while normal current I_1 flows to node B in reverse current
25 protection circuit 20, as will be explained later. From node B, normal current I_1 flows on to terminal 22 of process control device 24. Normal current I_1 flows through process control device 24 back through terminal 26 of process control device 24 to conductor 31. Normal
30 current I_1 flows from conductor 31 through reverse current protection circuit 20 to conductor 33 and on through overcurrent protection circuit 16 to node C of overcurrent protection circuit 16. At node C,

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overcurrent I_2 from current diverting means 38 is summed with normal current I_1 such that the entire loop current I_1+I_2 flows from node C out through terminal 40 back to loop 11.

5 Normal current I_1 flowing through process control device 24 induces potential V_2 across terminals 22 and 26. Potential V_2 is representative of polarity of loop current I_1+I_2 . Potential sense means 18 coupled across a portion of loop 11 senses potential V_2 and
10 generates output 3 indicative of potential V_2 . Potential sense means 18 diverts substantially no device current I_1 back to loop 11 when loop potential V_2 is a proper polarity. When potential sense means 18 senses loop potential V_2 to be the proper polarity, impedance
15 of variable impedance 30 is reduced in response to output 3 and normal current I_1 flows freely through process control device 24 and through variable impedance means 30 to overcurrent protection circuit 16. When, instead, potential sense means 18 senses potential V_2 as
20 reversed from the proper polarity or insufficient in magnitude, then impedance of variable impedance 30 is increased in response to output 3 thus reducing normal current I_1 flowing through process control device 24 and variable impedance means 30. Thus, reverse current
25 protection circuit 20, having variable impedance 30 conducting device current I_1 , is responsive to output 3 which is a function of a loop potential V_2 , the protection circuit 20 diverting substantially no device current I_1 back to loop 11 when loop potential V_2 is the
30 proper polarity.

Amplitude of normal current I_1 flowing through current sense means 34 controls the level of output 1. The variable impedance of current diverting means 38 is

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responsive to the level of output 1. When normal current I_1 flows at the predetermined upper level, output 1 reaches a level such that the impedance of current diverting means 38 is reduced so that shunt
5 current I_2 now flows through current diverting means 38 and also through current sense means 13, which is in series with current diverting means 38. The amplitude of shunt current I_2 flowing through current sense means 13 controls the level of output 2. The level of output
10 2, which is indicative of shunt current I_2 , controls the impedance of variable impedance 32. The impedance of variable impedance 32 controls the amplitude of normal current I_1 flowing from loop 11 in series through process control device 24 and variable impedance 32 such
15 that normal current I_1 does not exceed the predetermined normal range.

Hence, overcurrent protection circuit 16, which senses the magnitude of device current I_1 , prevents device current I_1 from exceeding a
20 predetermined upper limit which can damage or degrade the performance of process control device 24 even when loop current exceeds the predetermined upper limit. Further, the circuit induces a reduced potential drop in the two wire loop. Moreover, the circuit is relatively
25 insensitive to the impedance of the additional device 42.

FIG. 2 shows a schematic diagram of a second embodiment of two-wire process control instrument 46 wired in series with power source 44 and process control
30 device 42 to form two-wire loop 43 carrying a DC loop current. Instrument 46 comprises overcurrent protection circuit 52, reverse current protection circuit 54 and process control device 24 where the two circuits are

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interposed between the loop 43 and the process control device 24. Overcurrent protection circuit 52 passes only normal current or device current I_1 of loop current through reverse current protection circuit 54 to process control device 24. The remainder of the loop current, shunt current or overcurrent I_2 , is shunted by overcurrent protection circuit 52 back to loop 43. Overcurrent I_2 , as described later, generates an output which controls the impedance between nodes D and E to maintain the level of normal current I_1 , which flows between nodes D and E, in the normal range. Overcurrent I_2 is substantially zero until device current I_1 attains the predetermined upper limit.

Two-wire loop 43 provides varying DC loop current I_1+I_2 to terminal 12 of overcurrent protection circuit 52. Loop current I_1+I_2 flows from terminal 12 to node A. At node A, shunt current I_2 flows to resistor 50, while normal current I_1 flows to node B in reverse current protection circuit 54. At node B, normal current I_1 is passed on to terminal 22 of process control device 24. Normal current I_1 flows through process control device 24 to terminal 26 of process controlling device 24 and on to node D. Normal current I_1 flows from node D through node E to node C in overcurrent protection circuit 52. At node C, shunt current I_2 from transistor 68 is summed with normal current I_1 such that the entire loop current I_1+I_2 flows from node C out through terminal 40 of process control instrument 10 back to loop 43.

Normal current I_1 flowing through process control device 24 induces potential V_2 across terminals 22 and 26. Potential V_2 is representative of polarity of loop current I_1+I_2 . Enhancement type field-effect

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transistor (FET) 56 coupled across terminals 22 and 26 senses polarity of potential V_2 via resistor 94 across gate 80 and source 82. Substantially no device current is diverted back to loop 43 from gate 80 to source 82, unlike the leakage from a base to an emitter if a bipolar transistor were substituted for FET 56. Leakage current reduces the accuracy of process control instruments and is undesirable. When loop current $I_1 + I_2$ is of correct polarity, FET 56 is enhanced by potential V_2 and is turned on, where impedance across source 82 to drain 84 is substantially reduced to zero such that normal current I_1 flows freely through process control device 24 and FET 56 from source 82 to drain 84. Substantially no potential drop is induced in loop 43 by reverse current protection 54 when FET 56 conducts device current I_1 since impedance from source 82 to drain 84 is substantially zero in comparison with other loop impedances. When loop current $I_1 + I_2$ is reversed from the correct polarity such that damage to process control device 24 could occur, FET 56 operates in a depletion mode and is turned off, such that impedance from source 82 to drain 84 is increased thus substantially reducing normal current I_1 flowing through process control device 24.

Reverse current protection circuit 54 operates independently from overcurrent protection circuit 52 and can be interposed between loop 43 and overcurrent protection circuit 52 and conducting the loop current $I_1 + I_2$. It can also be interposed between loop 43 and process control device 24 when overcurrent protection circuit 52 is omitted thus conducting device current I_1 which here is the same as the loop current.

Normal current I_1 flowing from node E to node

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C through current sensing resistor 60 induces potential V_4 which is indicative of the amplitude of normal current I_1 . When normal current I_1 attains the upper limit of the normal operating range, potential V_4 across
5 base 68 to emitter 66 biases current diverting means bipolar transistor 62 on, which can also be a FET or the like. Biasing transistor 62 on allows shunt current I_2 to flow from node A through current sensing resistor 50, transistor 62 via collector 64 to emitter 66, and
10 resistor 90 to node C. Shunt current I_2 induces potential V_5 across resistor 50 which is indicative of the amplitude of shunt current I_2 . Resistor 50 can also comprise other current sensing means that generates a potential corresponding a current, such as a transistor.
15 Potential V_5 generates potential $V_6 = V_1 - V_5 - V_4$ across gate 74 and source 76 such that enhancement type FET 70, serving as a variable impedance, operates in a depletion mode and is turned off.

When FET 70 operates in the depletion mode,
20 impedance from drain 72 to source 76 is substantially increased and substantially all normal current I_1 flows from node D to node E through current limiting means resistor 58 instead of through FET 70 via the drain 72 to source 76, which is in parallel with resistor 58.
25 Resistor 58, or equivalent high impedance current limiting means, has a large power rating for dissipating a large amount of power when conducting the majority of device current I_1 . Resistor 58 has a value such that the sum of potentials V_2 , V_7 and V_4 induced by normal
30 current I_1 flowing at the upper limit is equal to terminal potential V_1 , thus limiting normal current I_1 to the upper limit. FET 70 can be substituted by a bipolar transistor; however, leakage current across the

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base to emitter of the bipolar transistor degrades accuracy of instrument 46.

When amplitude of normal current I_1 is below the upper limit of the normal range induced potential V_4 is insufficient to bias transistor 62 on, substantially
5 no shunt current I_2 conducts through resistor 50, potential V_5 is substantially zero and FET 70 is enhanced and turned on. Enhanced FET 70 has a reduced impedance of substantially zero from drain 72 to source
10 76 and substantially all normal current I_1 flows from node D to node E through FET 70 via drain 72 to source 76, instead of through resistor 58, and potential V_7 is reduced to substantially zero. Thus, the parallel combination of FET 70 and resistor 58 functions as a
15 variable impedance inducing a reduced potential drop for limiting device current I_1 to the normal range, and is responsive to potential V_5 , which is indicative of shunt current I_2 . During normal operation, the only substantial potential drop induced in loop 43 by
20 overcurrent protection circuit 52 is V_4 , which is substantially less than a potential drop of a typical forward biased diode. All other components require only minimal wattage ratings thus reducing cost, size requirements and increasing reliability. Further,
25 overcurrent protection circuit 52 operates independently of the impedance of power source 44, and does not highly stress any components while conducting normal current I_1 flowing at the upper limit.

Amplitude of normal current I_1 below the upper
30 limit generates a substantially reduced lift-off potential $V_1 = V_2 + V_4 + V_7$ compared to conventional protection circuits. Process control instruments having reduced lift-off potentials, such as the invention

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disclosed, are very useful for the industrial process control industry. First of all, the likelihood of generating sparks across terminals 12 and 40, which may ignite a combustible atmosphere, is reduced. Secondly, instrumentation with lower lift-off potentials increase the distance that a remote process control instrument can be located while operating from a safe power source level, such as that produced by power source 44. Protection circuits in process control instruments, such as the invention disclosed, that divert substantially no device current back to the loop during normal operation improve the accuracy of process control instruments.

Resistor 92, connected from node E to base 68 of transistor 62, along with resistors 90 and 94, provide intrinsic safety protection for overcurrent protection circuit 52 and reverse current protection circuit 54. The circuits, as disclosed, have no components capable of substantial energy storage, such as a capacitor or an inductor, that are capable of discharging with sufficient energy to provide a spark which can ignite an explosive atmosphere.

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WHAT IS CLAIMED IS:

1. A process control instrument, comprising:
a process variable controlling device
receiving a device current; and
a current protection circuit receiving a loop
current from a two wire loop and passing
a portion of the loop current as the
device current through the device no
greater than a predetermined upper
limit, comprising:
first current sensing means conducting
the device current between the loop
and the device for generating a
first output indicative of the
device current;
current diverting means coupled across
the loop responsive to the first
output for diverting a portion of
the loop current as a shunt current
back to the loop through a second
current sensing means for
generating a second output
indicative of the shunt current;
and
impedance means having a variable
impedance conducting the device
current and responsive to the
second output for limiting device
current.
2. The instrument of Claim 1 wherein the second
output controls the magnitude of the variable impedance.
3. The instrument of either Claims 1 or 2 wherein
the impedance means enables substantially all loop

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current to flow through the device when the loop current is no greater than the upper limit.

4. The instrument of any one of the preceding claims wherein the first and second current sensing means each comprise a separate resistor.

5. The instrument of any one of the preceding claims wherein the current diverting means comprises a transistor.

6. The instrument of any one of the preceding claims wherein the impedance means comprises a field effect transistor.

7. A process control instrument, comprising:
a process variable controlling device
receiving a device current from a two wire loop; and
a reverse current protection circuit
conducting the device current between the loop and the device, the protection circuit having potential sense means coupled across the loop for generating an output indicative of the sensed loop potential, and impedance means having a variable impedance conducting the device current and responsive to the output for inhibiting the device current from flowing through the device when the loop potential is reversed from a predetermined polarity, wherein the reverse current protection circuit diverts substantially no device current back to the loop when loop potential comprises the predetermined polarity.

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8. A process control instrument, comprising:
a process variable controlling device
receiving a device current; and
a current protection circuit receiving a loop
current from a two wire loop and passing
a portion of the loop current as the
device current through the device,
comprising:
current sensing means conducting the
device current for generating a sensor
output indicative of the device current;
current diverting means coupled across
the loop and responsive to the sensor
output for diverting loop current in
excess of a predetermined upper limit of
device current back to the loop when the
sensor output indicates the upper limit
is reached; and
reverse current protection means coupled
across the loop having a first variable
impedance conducting the device current
for inhibiting the device current from
flowing through the device when a loop
potential is reversed from a
predetermined polarity, where the device
current is limited to a current range
controlled by the first variable
impedance and the upper limit.
9. The instrument of Claim 8 wherein the current
diverting means further comprises a second variable
impedance conducting the device current for limiting the
device current to no greater than the upper limit.

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10. The instrument of either of Claims 8 or 9 wherein the first variable impedance is responsive to the loop potential and inhibits substantially all device current from flowing through the device when the loop potential is reversed from the predetermined polarity.

11. The instrument of any one of Claims 8, 9 or 10 wherein the current diverting means enables substantially all loop current to flow through the device when loop current is no greater than the upper limit and wherein the first and second variable impedance each comprises a separate field effect transistor, and the current sensing means comprises a resistor.

12. The circuit of anyone of claims 8, 9, 10 or 11 wherein the device current is within a device range of 4 to 20 milliamperes, and the device current and the loop current are substantially equal with the shunt current being substantially zero.

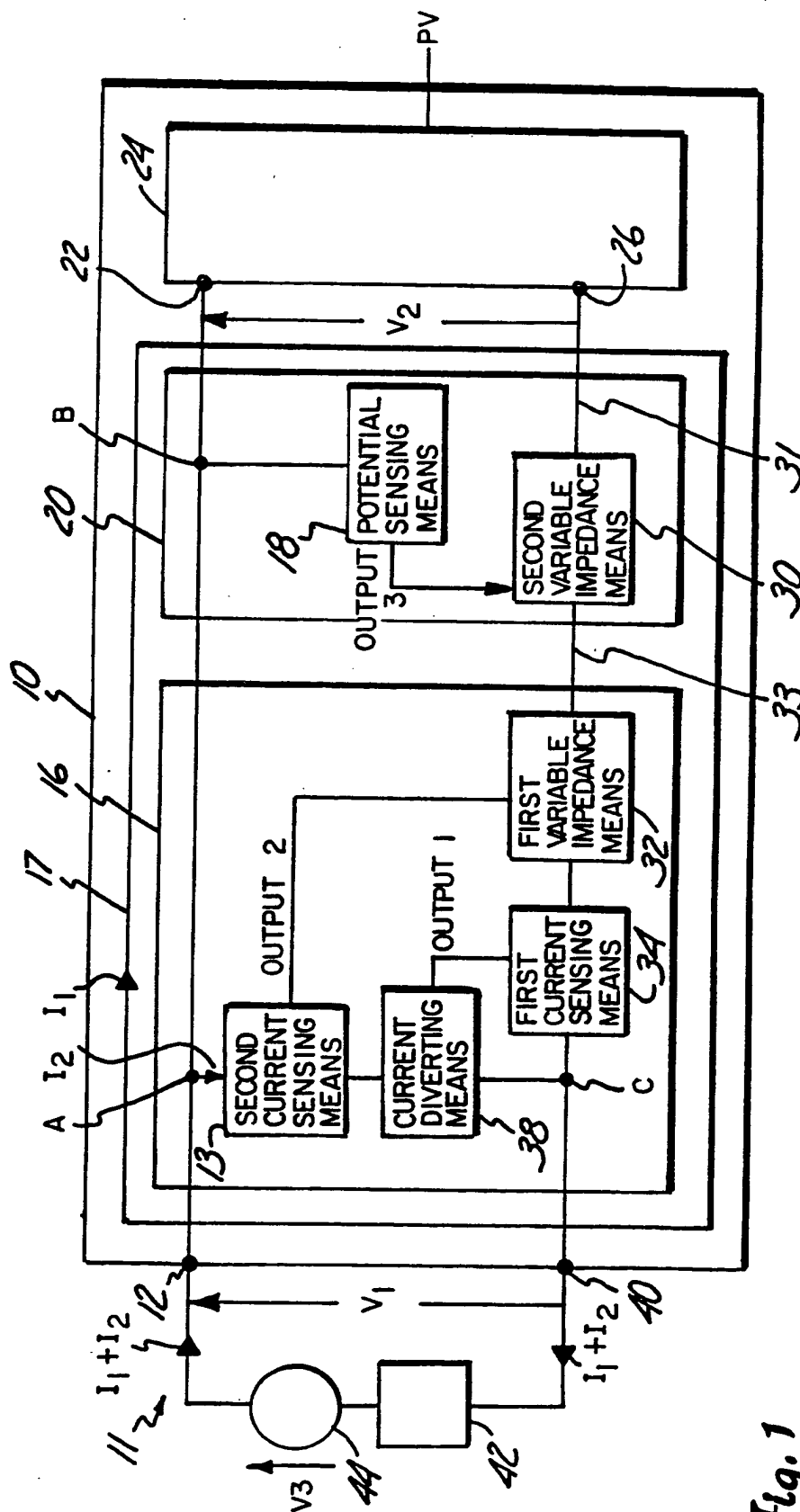
$\frac{1}{2}$ 

Fig. 1

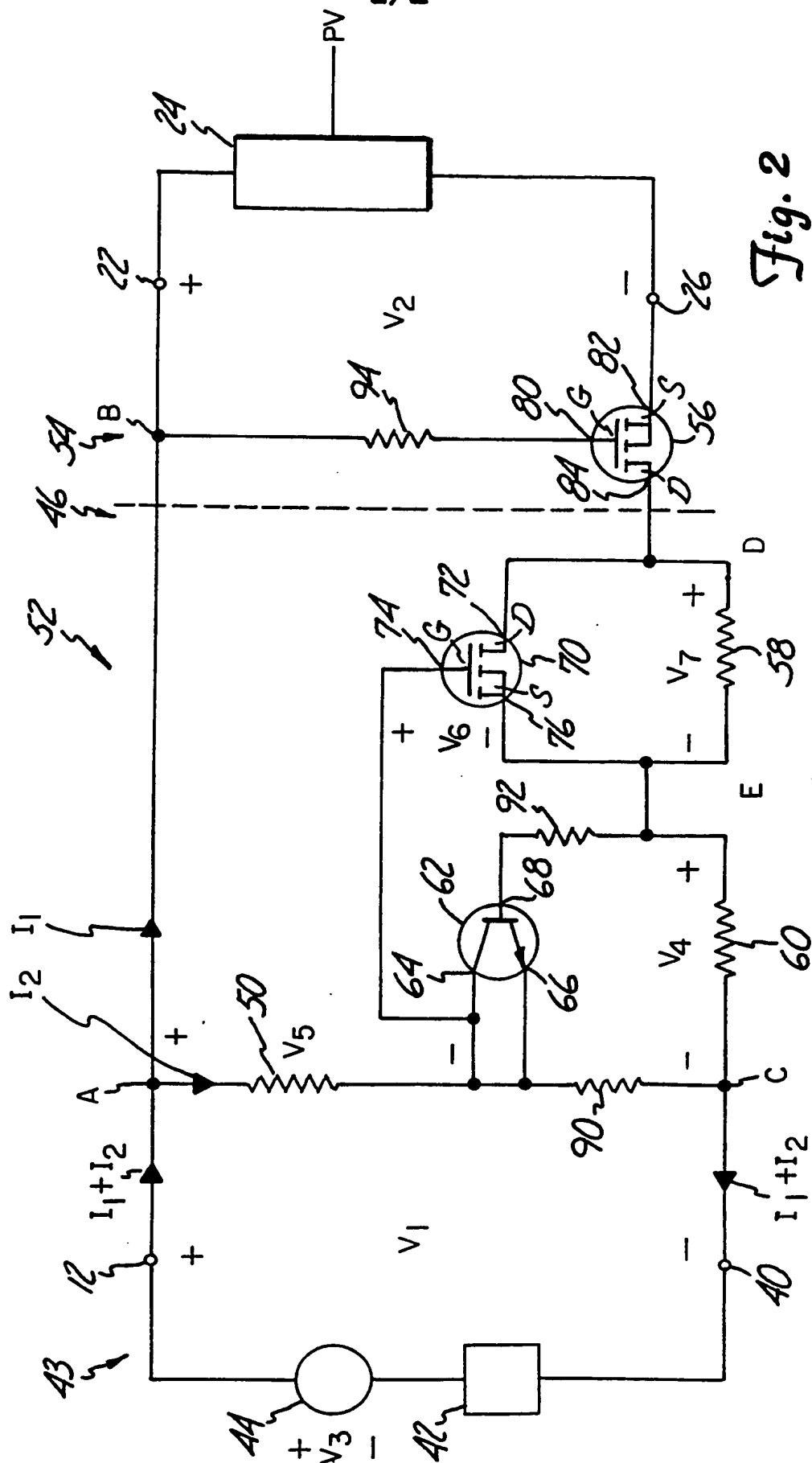


Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/05109

I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. Cl. 5 H02H 9/02
U.S. Cl. 361/18,56

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System

Classification Symbols

U.S. 361/18,56,58,91,111,84

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of Document, with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	US, A 3,582,713 (TILL) 16 MARCH 1970 see entire document	1-22
Y	US, A 4,857,985 (MILLER) 15 AUGUST 1989 see entire document	1-22

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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IV. CERTIFICATION

Date of the Actual Completion of the International Search

29 OCTOBER 1991

International Searching Authority

ISA/US

Date of Mailing of this International Search Report

14 NOV 1991

Signature of Authorized Officer

TODD E. DEBOER-Primary Examiner